successor to the *Hubble*, is scheduled for a 2013 launch into the L2 Lagrange point 1.5 million kilometers antisunward from Earth. "Its infrared capabilities will let us peer through dusty stellar nurseries and study the details of star formation," says Mather. "We also hope to see the first generation of supernovae."

Smoot was born in 1945 in northern Florida, in a town with the unlikely name of Yukon. Perhaps it presaged his later sojourns in colder climes: elementary school in Alaska and a 1991 trip to his Berkeley group's radio dish at the South Pole to measure galactic-foreground emission at wavelengths longer than *COBE* could see.

His undergraduate degree, as well as his PhD, is from MIT. "I'm often asked," says Smoot, "whether I'm the eponymous Smoot after whom the body-length unit of measure marked off in paint along the Harvard Bridge is named. The answer is no. *That* Smoot was my older and considerably shorter cousin Oliver."

A casual remark by Smoot at the press conference following the 1992 announcement of CMB fluctuations made him a media celebrity. Asked about the significance of the fluctuations for nonscientists, he answered, "If you're religious, this is like seeing God." Not long thereafter he attended an astrophysics meeting in England that happened to coincide with a major meeting of Anglican bishops. "Somehow in this ecclesiastical context I found myself on the BBC and front pages for two weeks."

Smoot is now a member of the *Planck* team. The European Space Agency's *Planck* observatory, much anticipated as *WMAP*'s successor, is scheduled for launch sometime next year. Like the Webb telescope, it is headed for the vicinity of L2. With finer angular resolution than *WMAP*, *Planck* should be able to measure CMB multipoles of order 2000. That's fine enough to reveal the CMB seeds of large galaxy clusters.

Bertram Schwarzschild

References

1. J. C. Mather et al., *Astrophys. J.* **354**, L37 (1990).
2. G. F. Smoot et al., *Astrophys. J.* **396**, L1 (1992).
3. Both laureates have published scientific memoirs: G. Smoot, K. Davidson, *Wrinkes in Time*, Morrow, New York (1993); J. C. Mather, J. Boslough, *The Very First Light*, Basic Books, New York (1996).
4. M. G. Hauser et al., *Astrophys. J.* **508**, 25 (1998).

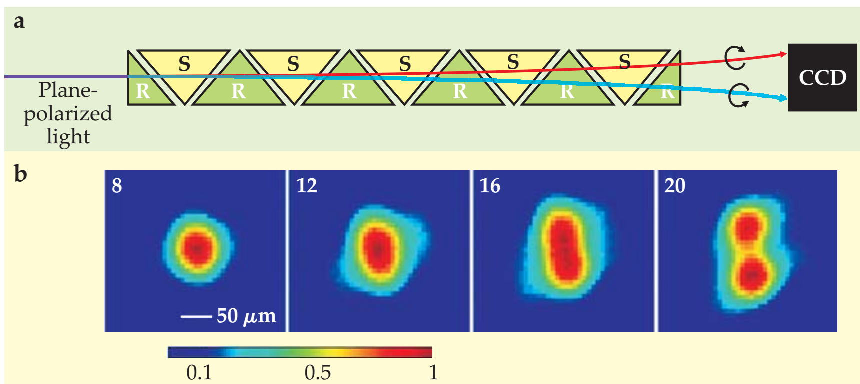
New angles to refraction and reflection in chiral liquids

A new experiment demonstrates one exception to a well-known rule: The angle of incidence is not always equal to the angle of reflection.

Augustin-Jean Fresnel predicted in 1822 that a light beam would split into two beams as it enters a chiral liquid—that is, one containing molecules that lack mirror symmetry. The splitting in a chiral liquid occurs because right-handed circularly polarized light and left-handed circularly polarized light travel at different speeds and hence see different indexes of refraction. Fresnel proposed an experiment to measure the angular splitting in a chiral solution, but the angle of splitting, on the order of microradians, is too small for Fresnel to have detected it. He did, however, observe the double image produced by light that had traversed a quartz crystal, which is birefringent because of its anisotropy. He used the effect to prove the existence of circularly polarized light.

Recently, Ambarish Ghosh and Peer Fischer of the Rowland Institute at Harvard University used a scheme similar to Fresnel's to measure the tiny angle of splitting between the two directions of polarization in a chiral liquid. Fischer said they were surprised that no one seems to have measured this angle before them. Perhaps, he thought, that's because previous research had focused on phase differences rather than beam positions.

One easily observable consequence of the accumulated phase difference between the two circularly polarized components is the rotation of polarization of plane-polarized light. Plane-polarized light is a coherent superposition of equal contributions of right- and left-handed circularly polarized light. Because one of the components travels more slowly than the other in a chiral liquid, a phase difference develops, causing the polarization vector of the superposition to rotate.



Beam splitting by chiral molecules. (a) Cuvettes filled with a solution of left-handed, or sinister (S), chiral molecules alternate with cuvettes of right-handed, or rectus (R), molecules. The net result of the arrangement is to increase the divergence of the right- and left-handed circularly polarized components of the incident plane-polarized light. **(b)** The splitting increases with the number of cuvettes (shown in the upper left of each image) until the two distinct beams are resolved. Color scale indicates intensity. (Adapted from ref. 1.)

Researchers today routinely use optical rotation to measure the concentration or the handedness of chiral molecules in solution. Much of organic stereochemistry is concerned with chiral molecules. Most drugs are chiral and are now marketed as single enantiomers—that is, molecules with the same chirality—because the mirror image can have a different effect on the human body.

To image the angular splitting, Ghosh and Fischer sent a plane-polarized light beam through a series of prismatic containers (cuvettes) filled in an alternating pattern with left-handed and right-handed enantiomers (see panel a of the figure). Because the angles at which the rays enter and leave a cuvette change along with the type of enantiomer filling that cuvette, the component rays diverge further at each interface. Panel b shows the image of the beams on a CCD camera after the light has traversed 8, 12, 16, and 20 angled interfaces, respectively.

Ghosh and Fischer used the multiple cuvettes shown in the figure to increase the spread of the refracted rays enough for the separate beams to be seen with a CCD camera. But the experimenters were also able to measure splitting that occurs at a single interface using a position-sensitive detector, which recorded the tiny movement of a laser beam after it had traversed the interface. Simultaneous modulation of the laser beam's polarization between right- and left-handed circular light permitted the detection of beam movements as small as 10 nanoradians.

With such a detector, the experimenters determined the angle of reflection of light that bounced off a single interface from within a chiral liquid. Contrary to the lesson taught in school, the angle of incidence in this case is not equal to the angle of reflection. No great principle is being violated. The experimenters explain that the handedness of the circularly polarized light changes upon reflection, so that the reflected light sees a different refractive index n than the incident light. From the boundary conditions on the electromagnetic waves at the interface, one arrives at a requirement equating the tangential components of the incident and reflected wavevectors, k_i and k_r. Thus, the condition $k_i \sin\theta_i = k_r \sin\theta_r$ governs the reflection.

The splitting at a single surface is a measure of the sample's circular birefringence—that is, the difference in refractive index seen by the two circularly polarized beams. Ghosh and Fischer found that the circular birefringence measured by the angular splitting is consistent with that determined by conventional optical-rotation measurements. Thus, they note, the two techniques yield equivalent information. In optical rotation, however, the magnitude of the rotation of the polarization vector is proportional to the distance traveled through the sample. By contrast, angular splitting is determined at the surface and is independent of the sample thickness. The angular splitting technique thus might hold promise for use with very small samples, such as are required in microfluidics or thin films.

Barbara Goss Levi

Reference

1. A. Ghosh, P. Fischer, *Phys. Rev. Lett.* **97**, 173002 (2006).

Superconductor forms domains that break time-reversal symmetry

Two interference experiments—one using the Kerr effect, the other using the Josephson effect—confirm strontium ruthenate's exotic pairing.

When a superconductor's temperature drops below its critical value, some of the most loosely bound electrons assemble into a single, Bose–Einstein ground state. Locked together, the electrons flow through the lattice with unimpeded ease.

To reach that remarkable state, electrons, being fermions, must pair up to form bosons whose total spin S is an integer. Pairs of spin-1/2 electrons have two choices of S: 0 or 1, antiparallel or parallel. Because a pair of identical fermions must have an antisymmetric wavefunction, fixing S also constrains the pair's total orbital angular momentum L: If $S = 0$, L must be an even integer; if $S = 1$, L must be an odd integer.

How electrons follow those rules and actually pair up depends on the symmetry of the lattice and on what fluctuations polarize and nudge the electrons together. In ordinary, Bardeen-Cooper-Schrieffer superconductors, lattice vibrations mediate the pairing and S and L are both zero. By analogy with atomic orbitals, the pairing is known as *s*-wave.

When L is nonzero, the paired electrons, like electrons in single atoms, can orbit each other in more than one configuration. No one has yet identified the mediating fluctuations in high-T_c cuprates, but experiments have established that the pairing is a cloverleaf-shaped variety of *d*-wave ($S = 0$; $L = 2$).

Yoshiteru Maeno of Kyoto University discovered strontium ruthenate's superconducting state in 1994. Strontium ruthenate (Sr_2RuO_4) has the same lattice structure as lanthanum cuprate (La_2CuO_4), the parent compound of the first family of high-T_c superconductors. Based on the resemblance, one might expect the ruthenate's superconductivity to occur in the RuO_4 planes and its pairing to be *d*-wave.

The superconductivity turned out to be two-dimensional, but the preponderance of evidence soon favored *p*-wave pairing ($S = 1$; $L = 1$). Indeed,